A-LEVEL PHYSICS • EXERCISE SHEET

16.2 The first law of thermodynamics

Name: ______________ Class: __________ Date: ____________ **Total: 16 marks**

Objective

Build the skills to answer exam questions on the **first law of thermodynamics** and work done by/on a gas.

You must be able to:

- state the **two ways** to change a system's internal energy
- use $W = p\Delta V$ and the **sign** of work done on vs by a gas
- use the **first law** $\Delta U = q + W$ and apply it to real situations

1 Worked examples

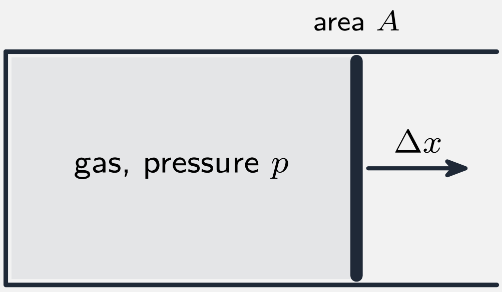
Study these first. Each one shows the method for a question type used later —follow the steps and you can do the Practice and Exam-style questions yourself.

■ Two ways to change internal energy

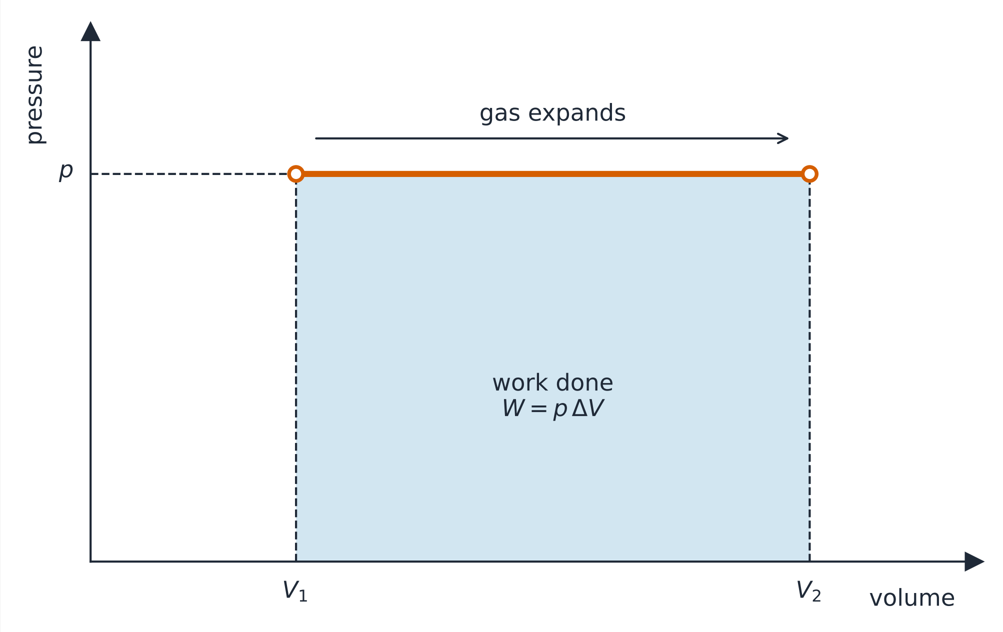
The internal energy of a system changes only by **heating it** (energy q) or by **doing work on it** (work W). The **first law** combines them.

■ Work done by a gas

At constant pressure, a gas changing volume does work:



$$W = p\,\Delta V = pA\,\Delta x$$



Work done by a gas is the area under p-V

$$W = p\Delta V.$$

First law of thermodynamics

$$\Delta U = q + W,$$

where ΔU = increase in internal energy, q = energy added **by heating**, W = work done **on** the gas.

- **compressed:** W on the gas is **positive** (gas gains energy);
- **expands:** W on the gas is **negative** (gas does work on surroundings);
- **constant volume:** $W = 0$, so $\Delta U = q$.

Worked example. A gas at 1.0×10^5 Pa expands from 2.0 to 5.0×10^{-3} m^3: work done **by** the gas $= p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300$ J.

Applying the first law

Worked example (a bicycle pump warms up). Air is compressed **quickly**, so almost no heat escapes ($q \approx 0$). Work is done **on** the gas ($W > 0$), so $\Delta U = q+W > 0$ —the internal energy and therefore the **temperature rise**. (An expanding gas does the opposite —it **cools**.)

2 Practice

Now apply the methods above.

2.1 State the **two ways** in which the internal energy of a system can be changed. [2]

2.2 Write the formula for the work done when a gas changes volume at **constant pressure**. [1]

2.3 A gas at 1.0×10^5 Pa expands by 3.0×10^{-3} m^3. Find the work done **by** the gas. [2]

2.4 State the **sign** of the work done **on** a gas when it is **compressed**. [1]

3 Exam-style questions

3.1 When a gas is **compressed**, the work done **on** the gas is: [1]

- **A** negative
- **B** zero
- **C** positive
- **D** undefined

3.2 A gas is heated with 500 J of energy, and 200 J of work is done **on** it. Find the change in **internal energy**. [2]

3.3 A gas at constant pressure 2.0×10^5 Pa is **compressed** from 4.0×10^{-3} to 1.0×10^{-3} m^3, while 800 J is removed by cooling. Calculate the change in internal energy ΔU. [4]

3.4 Use the first law of thermodynamics to explain why a bicycle pump becomes **warm** when air is pumped quickly. [3]

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **16.2 The first law of thermodynamics** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/43 N25 —Q2 (first law, bicycle pump)
- 9702/42 J25 —Q3 (work done by a gas)
- 9702/41 J25 —Q4 (first law)
- 9702/42 M25 —Q3 (thermodynamics, structured)
- 9702/43 J25 —Q4 (internal energy and work)

Solutions

2.1 By **heating** it (transferring thermal energy to it) and by **doing work** on it.

2.2 $W = p\Delta V$.

2.3 $W = p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300$ J.

2.4 **Positive**.

3.1 **C** —positive.

3.2 $\Delta U = q + W = 500 + 200 = 700$ J.

3.3 Compressed $\rightarrow$ work done **on** gas is positive: $W = p|\Delta V| = (2.0 \times 10^5)(3.0 \times 10^{-3}) = 600$ J; cooling removes energy, so $q = -800$ J; $\Delta U = q + W = -800 + 600 = -200$ J.

3.4 The air is compressed quickly, so little heat leaves ($q \approx 0$); work is done **on** the gas, so W is positive; by $\Delta U = q + W$, $\Delta U > 0$, so the internal energy and temperature **rise** —the pump feels warm.